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02 August 2018

Version of attached file:

Accepted Version

Peer-review status of attached file:

Peer-reviewed

Citation for published item:

Durrand, J. W. and Wagstaff, K. and Kasim, A. and Cawthorn, L. and Danjoux, G. R. and Kothmann, E. (2018) 'Reliability of repeated arm-crank cardiopulmonary exercise tests in patients with small abdominal aortic aneurysm.', *Anaesthesia*, 73 (8). pp. 967-971.

Further information on publisher's website:

<https://doi.org/10.1111/anae.14312>

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Reliability of repeated arm-crank cardiopulmonary exercise tests in patients with small abdominal aortic aneurysm*

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*Presented in part at the Vascular Anaesthesia Society of Great Britain and Ireland Annual Scientific Meeting, Glasgow, September 2014.

Running title: Reliability of arm-crank CPET in patients with small aneurysms

Keywords: arm ergometry; CPET; preassessment; vascular surgery; abdominal aortic aneurysm

Summary

Arm-crank ergometry may be useful in patients unable to pedal, for instance due to peripheral arterial disease. Twenty participants with small abdominal aortic aneurysm undertook two serial arm-crank tests and then a pedal test, four of whom had indeterminate anaerobic thresholds, precluding analysis. The mean (sd) peak arm and leg oxygen consumptions in 16 participants were: 13.71 (2.62) ml.kg⁻¹.min⁻¹ and 16.82 (4.44) ml.kg⁻¹.min⁻¹, with mean (sd) individual differences of 3.11 (2.48) ml.kg⁻¹.min⁻¹, $p = 0.0001$. The respective values at the anaerobic thresholds were 7.83 (1.58) ml.kg⁻¹.min⁻¹ and 10.09 (3.15) ml O₂.kg⁻¹.min⁻¹, with mean (sd) individual differences of 2.26 (2.34) ml O₂.kg⁻¹.min⁻¹, $p = 0.0001$. The correlation coefficients (95% CI) for peak oxygen consumption and anaerobic threshold were 0.88 (0.62-1.0) and 0.70 (0.32-1.0). There were no significant differences in serial arm-crank tests, with intra-cluster correlations (95% CI) of 0.87 (0.86-0.88) and 0.65 (0.61-0.69) for peak oxygen consumption and anaerobic threshold, respectively.

Introduction

The assessment of physical fitness and patient risk before major surgery is a significant challenge for peri-operative clinicians [1]. This is a particular issue in patients scheduled for major vascular surgery, which is common in elderly patients who have concomitant chronic health conditions that increase the risk of postoperative harm.

Cardiopulmonary exercise testing can be used to predict outcome in non-cardiac surgical populations [2, 3], including patients scheduled for repair of intact abdominal aortic aneurysm [4, 5], a group for whom we have reported the reliability of anaerobic threshold on repeat testing [6]. Some patients are unable to pedal, due to various reasons including musculoskeletal disease and occlusive peripheral arterial disease, which is why there is interest in arm exercise to measure fitness, which correlates with results from leg exercise [7-9]. The absolute physiological values measured by arm and leg methods differ, as legs are bigger than arms and an arm crank is mechanically different to a bicycle. However, the relationship between arm and leg values may be sufficiently consistent to use one to estimate the other.

An important initial investigation is to determine the reliability of arm crank measurements. Several factors may influence serial measurements in an individual, including equipment reliability, changes in participant fitness levels, a 'learning effect' with repeat testing and motivation. Although encouraging reproducibility has been demonstrated in healthy volunteers [7] we could not identify previous studies in high-risk surgical populations.

The primary aim of this study was to examine the reliability of arm crank peak oxygen consumption and anaerobic threshold in patients with intact abdominal aortic aneurysm. Our secondary aim was to determine the correlations of arm and leg measurements.

Methods

The Durham and Tees Valley research ethics committee approved this study. We recruited patients with abdominal aortic aneurysm < 5.5 cm diameter by ultrasound measurement between January and March 2013. We did not study patients in whom cardiopulmonary exercise testing was contra-indicated [10], those unable to pedal or turn an arm crank, or patients with peripheral arterial disease or an acute illness.

All participants provided written informed consent. We recorded participant age, sex, height, mass, medical history and medications. An anthropometric method was utilised to estimate and allow correction for appendicular skeletal muscle mass (ASM) [11, 12]. We measured arm length from the tip of the acromion to the tip of the middle finger and leg length from the greater trochanter to the floor. Limb circumference and skin fold thickness were measured at the midpoint of the upper arm and thigh, from which we estimated limb muscle circumference: limb circumference – ($\pi \times \text{skinfold thickness}$).

Participants performed cardiopulmonary exercise tests at the same time of day on three occasions. The sequence was an arm crank test, a second arm crank test and a cycle ergometer test. Participants abstained from new or strenuous physical activity before each test and took their usual medications. At least seven days separated a test from the preceding one.

Two ALS-certified investigators supervised symptom-limited maximal testing after calibrating flow and gas sensors [10, 13]. The protocol was three minutes of rest, three minutes of unloaded exercise and a ramped increase in load. Participants sat in a static chair with elbows slightly flexed in the extended position during cranking (Lode Angio Arm ergometer, BV Medical Technology, Groningen, The Netherlands). The arm crank height and distance were replicated for the second test. Participants maintained a cadence of 60-70 rpm and the load increased by 5 W.min⁻¹ during the incremental ramp [13]. The cycle ergometer saddle height was set for slight knee flexion in the extended position during pedaling (Lode, BV Medical Technology, Groningen, The Netherlands). A cadence of 60-70 rpm was maintained and the incremental load was set at 10-20 W.min⁻¹. We measured blood pressure and pulse during and after exercise, until they were less than 120% of resting values. For all three tests we used the same gas analysis (Medgraphics Ultima system, Tewkesbury, Gloucestershire, UK) to measure oxygen consumption ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$) and minute ventilation.

Two investigators (GD and EK), blinded to participant identity and test sequence, independently determined the anaerobic threshold with the modified V-slope method [14]. When there was disagreement, the readers examined the test output in detail together and attempted to reach a consensus. If consensus could not be achieved, the graphs of $\dot{V}O_2$ and $\dot{V}CO_2$ against time were re-examined to confirm that the $\dot{V}CO_2$ was consistently less than the $\dot{V}O_2$ before the start of exercise. If not, the participant was judged to have been hyperventilating, in which case the anaerobic threshold was not identified [15].

We calculated that 16 participants would provide 80% power to detect arm crank test-retest reliability, defined as an intra-class correlation coefficient of at least 0.74 for the anaerobic threshold at a significance level of 5% [6, 16]. We decided to recruit 20 participants in case of attrition. We used a multiple linear regression model to assess the association of peak oxygen consumption and anaerobic threshold measured by arm crank with those measured by cycle ergometry. Measured values were adjusted for age, BMI, corrected limb circumference and muscle volume by their inclusion as covariates in the regression model. Intra-cluster correlation was calculated using a random effects model [17]

Results

We recruited 21 participants. Three tests were completed by 20 participants, four of whom had indeterminate anaerobic thresholds, which we did not analyse (Table 1).

The mean (sd) peak $\dot{V}O_2$ and anaerobic thresholds measured on first and second arm crank tests were: 13.76 (3.00) ml.kg⁻¹.min⁻¹ and 13.80 (2.84) ml.kg⁻¹.min⁻¹, with mean (sd) individual differences of 0.26 (1.67) ml.kg⁻¹.min⁻¹, $p = 0.52$; and 7.68 (1.82) ml.kg⁻¹.min⁻¹ and 7.91 (1.56) ml.kg⁻¹.min⁻¹, with mean (sd) individual differences of 0.04 (1.48) ml.kg⁻¹.min⁻¹, $p = 0.90$. The intra-class correlation coefficients (95% CI) for peak $\dot{V}O_2$ and anaerobic threshold were 0.87 (0.86-0.88) and 0.65 (0.61-0.69), respectively.

The mean (sd) peak $\dot{V}O_2$ measured by arm crank and bicycle were: 13.71 (2.62) ml.kg⁻¹.min⁻¹ and 16.82 (4.44) ml.kg⁻¹.min⁻¹, with mean (sd) individual differences of 3.11 (2.48) ml.kg⁻¹.min⁻¹, $p = 0.0001$ (Fig. 1). The mean (sd) oxygen consumptions at the anaerobic threshold measured by arm crank and bicycle were: 7.83 (1.58) ml.kg⁻¹.min⁻¹ and 10.09 (3.15) ml.kg⁻¹.min⁻¹, with mean (sd) individual differences of 2.26 (2.34) ml.kg⁻¹.min⁻¹, $p = 0.0001$ (Fig. 2). The correlation coefficients (95% CI) for peak $\dot{V}O_2$ and anaerobic threshold were 0.88 (0.62-1.0) and 0.70 (0.32-1.0).

A number of variables were independently associated with oxygen consumption during arm cranking (Table 2), which together accounted for 79% of the variation (r^2) in arm crank values.

Discussion

We found that, in patients with abdominal aortic aneurysm without peripheral arterial disease, oxygen consumption during arm-crank exercise is associated with the higher oxygen consumption during pedaling. These results are consistent with those reported in studies of healthy volunteers [7-9].

Peak oxygen consumption was more consistent than that at the anaerobic threshold on retesting, which may be because identification of the anaerobic threshold is less objective [18]. However, peak oxygen consumption is dependent upon patient motivation and test termination criteria. The correlation for peak and anaerobic arm-crank oxygen consumption were comparable to those for pedaling [6].

It is unclear how directly values measured during arm-ergometry could be extrapolated into clinical decisions that are usually dependent upon leg-ergometry values: our study was of insufficient size to test the clinical utility of arm ergometry. A proportion of patients – scheduled for vascular and other operations – are unable to pedal, leaving the clinician to guess their aerobic fitness or use alternative tools to estimate fitness. A larger study in patients with aneurysms may allow determination of continuous or discontinuous relationships between arm ergometry values and peri-operative risks, corresponding to those established for leg ergometry. This in turn would allow investigation of the predictive value of arm-crank measured physiological parameters and use in clinical risk stratification. There is insufficient evidence to support this at present.

We acknowledge three important limitations to our study. First, our participants were recruited from a single centre, restricted to those with abdominal aortic aneurysm under surveillance: we do not know if our results would be replicated in other patient populations and places. Second, we did not study participants unable to pedal, which is the group for whom arm-crank ergometry would be required. Finally, results of any test in an individual vary, due to patient, environmental and equipment factors, a variability that might require more than a single repeated measure to fully explore.

In conclusion, this study is a step towards validating arm-crank cardiopulmonary testing as an alternative to pedaling in surgical patients.

Acknowledgements

No external funding and no competing interests declared.

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Table 1 The characteristics of 16 participants who completed three cardiopulmonary exercise tests; two by arm crank and one cycle ergometer. Values are number (proportion) or mean (SD).

Age; years	69.7 (6.7)
Height; cm	175.6 (5.9)
Weight; kg	89.5 (19.4)
BMI; kg.m⁻²	28.9 (5.1)
Arm	
Length; cm	76.2 (3.9)
Circumference; cm	31.1 (3.1)
Skin thickness; mm	12.2 (5.5)
Leg	
Length; cm	92.0 (12.4)
Circumference; cm	51.8 (8.0)
Skin thickness; mm	9.0 (3.7)
AAA diameter; cm	3.7 (0.7)

AAA, abdominal aortic aneurysm; BMI, body mass index

Table 2 Multiple linear regression for the association of variables with oxygen consumption ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) measured by arm crank (mean of two tests), the peak value and at the anaerobic threshold. Value are the change in arm crank measurement in $\text{ml} \text{O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ for a unit change in the independent variable.

Independent variable	Peak oxygen consumption		Anaerobic threshold	
	Coefficient (95% CI)	p value	Coefficient (95% CI)	p value
Cycle; $\text{ml} \text{O}_2 \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$	0.38 (0.16-0.60)	0.003	0.23 (0.04-0.42)	0.02
Age; y	-0.12 (-0.23 to -0.02)	0.02	-0.14 (-0.22 to -0.05)	0.004
BMI; $\text{kg} \cdot \text{m}^{-2}$	-0.21 (-0.48 to 0.06)	0.12	-0.01 (-0.20 to 0.17)	0.86
Arm				
Muscle circumference; cm	-0.01 (-0.41 to 0.38)	0.94	-0.21 (-0.50 to 0.08)	0.13
Muscle volume; cm^3	-0.01 (-0.07 to 0.05)	0.65	-0.04 (-0.17 to 0.10)	0.57

BMI, body mass index

Figure 1 The association of the peak oxygen consumption measured by arm crank (mean of two measurements) vs. bicycle, depicted by regression line (— — —) and 95% CI (— — —).

Figure 2 The association of the oxygen consumption at the anaerobic threshold measured by arm crank (mean of two measurements) vs. bicycle, depicted by regression line (— — —) and 95% CI (— — —).